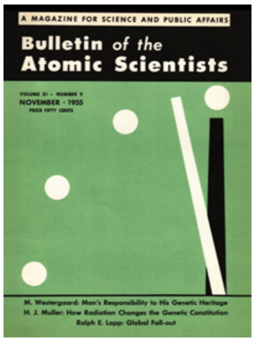

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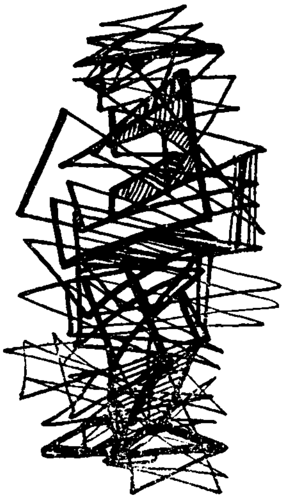
Global Fall-out

RALPH E. LAPP

This is the fourth article in Dr. Lapp's series on radioactive fall-out.



WHEN the United States exploded its superbombs at Bikini in the spring of 1954, there was a resultant radioactive contamination of global dimensions. In fact, easily measured quantities of radioactive debris are still circling the planet, falling-out on England, Russia, and Japan, to name but a few sites where measurements have been made.

The matter of global fall-out excited much concern all over the world. It popped up in the House of Commons last spring. Concern over the fall-out and genetics effects prompted an inquiry to Ian MacLeod, the British Minister of Health. "This is indeed a strange and difficult subject to debate. . . ." he began. Surely, it was "strange" for Mr. MacLeod to talk about the effects of American bomb explosions halfway around the globe. No doubt, it was "difficult" to discuss a hazard most accurately described in roentgen dose, counts per minute, and micromicrocuries per liter.

Quite apart from the strangeness and difficulty of the subject, there was and still is a double security bar to intelligent discussion of the radioactive hazard.

First, the measurements of global or remote radioactive fall-out are highly classified. They rarely appear in the open scientific literature. Russia, Britain, and the USA are all known to have far-flung and elaborate long-range detection systems for analysis of each other's bomb tests. The seismic shock, atmospheric pressure pattern, and radioactive debris of a nuclear explosion leave identifiable footprints. Probably the most unique evidence pointing to a nuclear explosion is gained by analysis of air samples taken by patrol aircraft. Such planes, equipped with air scoop-filters, can bring to earth samples sufficiently "hot" to permit the application of radiochemical techniques. It was in this way that Joe I—the first Soviet A-bomb test—was tracked down in August of 1949.

Japanese scientists have been monitoring nuclear explosions using a variety of techniques. Their publications have been most useful to U.S. scientists. Indeed, were it not for Japanese reports on fall-out the world would probably still be in the dark about the lethality of local fall-out.

Second, appreciation of the radioactive hazard must be based upon a realistic knowledge of the nature of the weapon producing the radioactivity. As long as one dealt only with pure A-bombs the hazard was easy to assess. And if one had only to contend with pure H-bombs there would be no real difficulty in estimating the hazard. Were the H-bomb to be a pure fusion weapon the most significant radioactivity would originate in the relatively small triggering A-bomb. But the H-bomb turned out to be an immensely radioactive device. The title "H-bomb" is something of a misnomer. Perhaps the best generic term is the "N-bomb" where the N stands for neutron. However, this terminology would also hold for an A-bomb. Thus, it is sensible to go back to the earliest name "Super" in connection with supra-megaton bombs.

While we lack detailed published data on systematic fall-out measurements, we do have good data on the nature of the superbomb. In fact, these data were in the possession of the *Bulletin of the Atomic Scientists* as long ago as August of 1954. The *Bulletin* has published three semi-technical articles describing the radioactive effects of the superbomb but until now it has refrained from publishing original material about the nature of the weapon. Perhaps this policy of caution and self-censorship was ill-advised for it led to a charge that the *Bulletin* was "leaked" information by AEC sources.

FORTUNATELY, Sir John Cockcroft pointed toward the true nature of the superbomb. In his address on "Radiological Hazards from Nuclear Explosions and Nuclear Power" (April 20, 1955) he stated: "The most important source of contamination is the hydrogen bomb since it produces 100–1,000 times more radioactive products than an atomic bomb. The contamination, however, is of the same kind. The same radioactive fission products are produced and their activity decays in the same way."

Professor Rotblat (see May *Bulletin*) pinpointed the problem more precisely and identified the culprit in the H-bomb as U-238. Fission products of plentiful U-238 (99.3 per cent of natural uranium) would be very much the same as those from costly U-235.

Convincing evidence that the superbomb derived a good chunk of its wallop from ordinary uranium was supplied by the Japanese scientists much before these two disclosures. For example, Professor K. Kimura of the University of Tokyo had analyzed the Bikini ash or fall-out residue on the decks of the *Lucky Dragon* and early in the summer of 1954 he had identified uranium-237. Incidentally, this

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[1] For articles one, two, and three, respectively, see *Bulletin*, November 1954, pp. 349–51; February 1955, pp. 45–51; and June 1955, pp. 206–09, 230.

isotope of uranium was a prewar Japanese discovery, as was the fission product Ruthenium 103. No wonder Professor Kimura observed: "It was truly a source of profound emotion when, during the present (fall-out) experiments, the nuclides Ru^{103} and U^{237} were unexpectedly again encountered."

To the nonphysicist readers of the *Bulletin* we hasten to explain the significance of U^{237}. This isotope does not occur in nature and must be produced artificially using a cyclotron as the Japanese did before the war, or a bomb as the Americans did on March 1, 1954. Neutrons released in this bomb could produce U^{237} by being absorbed in U^{238}. Technically, it's called an (*n*, 2*n*) reaction, meaning that one neutron enters the nucleus of U^{238} and two fly out. The resulting U^{237} is highly radioactive and decays with a half-life of about a week. More than just proving that U^{238} fissions in the superbomb, the presence of U^{237} means that many of the bomb's neutrons must have had an energy in the range of 10 Mev (million electron volts) or higher. This, in turn, leads to the conclusion that these fast neutrons were the end product of a (*d*, *t*) reaction, i.e., deuterium-tritium fusion. Bomb-produced tritium has been measured by U.S. scientists using rain water as a sample source. The latter would correspond to the H-phase of the superbomb.

The important fact to bear in mind is that the Bikini superbomb of March 1, 1954 derived the *major* portion of its energy from fission of U^{238}. This does not immediately follow from the foregoing presentation since the argument has been of a qualitative nature. However, it is readily deduced from applying this knowledge to the data given in the AEC's fall-out press release of February 15, 1955. One simply plots the cigar-shaped areas of fall-out for the various roentgen doses given by the AEC, adjusts the 36-hour dose rate to an eternity dose, and then integrates the number of eternity roentgen square miles of fall-out radioactivity. This calculation yields a figure of 5 megatons of fission products (i.e., the fall-out associated with a 5 million ton fission explosion) in the area of fall-out. If we assume that 50 per cent of the radioactive debris fell out then this would mean that the fission energy yield in the March 1st bomb was 10 megatons. On the assumption that the total (i.e., fission plus fusion) yield of the bomb was 15 megatons, this would mean that two-thirds of the bomb's power came from uranium fission.

Dr. Willard F. Libby's specific assumption of "a nuclear explosion releasing 10 megatons of fission energy" in his speech of June 3, 1955 (Sept. *Bulletin*, p. 257) seems consonant with the above estimate. Clearly, it is the most substantial official confirmation of the radical assumption that the superbomb taps the energy of U^{238}.

Thus we may proceed to analyze the global fall-out with a sense of confidence in our calculations. While we do not profess to know precisely the ratio of fission to fusion energy release in present bombs, we side-step this obstacle by making all calculations in terms of megatons of fission energy release.

TABLE 1[*]

RADIATION DOSAGE FROM GLOBAL FALL-OUT (NUCLEAR)

TEST SERIES		NUMBER OF BOMBS	DOSAGE FROM 1ST TRANSIT[**]	RESIDUAL DOSAGE	TOTAL DOSAGE
Origin	Date				
Nevada, USA	Spring 1951	5	0.06 mr	0.10 mr	0.16 mr
Nevada, USA USSR	Autumn 1951	9	1.05 mr	0.10 mr	1.15 mr
Nevada, USA	Spring 1952	8	0.30 mr	0.06 mr	0.36 mr
Nevada, USA	Spring 1953	11	1.13 mr	0.32 mr	1.45 mr
USSR	Autumn 1953	4	0.29 mr	0.09 mr	0.38 mr
USSR	Autumn 1954	7	0.38 mr	0.18 mr	0.56 mr
Nevada, USA	Spring 1955	14	0.20 mr	0.08 mr	0.28 mr
Adjustment (nominalization)		12	——	——	0.80 mr
	TOTALS	70	3.41 mr	0.93 mr	5.14 mr

We are primarily concerned with the roentgen dose received at some point remote from the explosion site. On the other hand, we cannot neglect consideration of the local dosage. For one thing, the local fall-out may involve much more severe dosage in terms of man-roentgens than the more remote fall-out. This is true because of the "freshness of the fission products" and the high population densities close to strategic targets. For another, we must realize that one of the prime factors influencing the remote fall-out is the type of bomb burst. Bombs burst close to the earth's surface maximize local fall-out and produce rather erratic global fall-out.

In the case of surface or near surface bursts the amount of local fall-out will depend upon the bomb size, weapon composition, altitude of burst, nature of the substratum, local meteorology, and other factors. The local fall-out has been discussed in previous articles (*Bulletin*, October 1954, February 1955, June 1955). It will be noted that the mechanisms whereby the highly radioactive fission products in the fireball "plate" out on substratum debris are not fully understood.

The fission products of uranium comprise about three dozen different elements and total more than two hundred different nuclear species with varying decay rates. So far as remote fall-out is concerned we can rule out the short-lived radioisotopes, i.e., fission products with half-lives measured in hours. The gross decay of fission products has been explained in Figure 3 of the article "Radioactive Fall-out" appearing on page 49 of the February *Bulletin*. The accumulated total dose from these fission products appears in Figure 2 on page 47 of the same article. In applying this dose curve to remote fall-out it is necessary to introduce certain corrections.

Let us visualize the process of remote fall-out from the invisible and widely dispersed bomb cloud remnants. The fission products will be carried on small particles of the substratum. That fraction of the fission products born in gaseous form (krypton and xenon, for example) may have diffused out of the original fireball without "plating" out on debris. The rate[2] at which the debris falls out of the "cloud" will depend upon the particle size distribution of the debris, upon atmospheric turbulence, the original meteorology, and upon the poorly understood processes whereby fractionation of specific radioelements occurs.

[*] Adapted from Harwell Report AERE-HP/R 1701 (June 1955).

[**] Meaning the surface dose delivered by the first circuit of the bomb cloud in its trip around the world. Dose thereafter is given under residual column. All measurements made in Britain.

TABLE 2*

RADIATION DOSAGE FROM GLOBAL FALL-OUT (THERMONUCLEAR)

TEST SERIES		DOSAGE INTERVAL	DOSE
Origin	Date		
Eniwetok, USA	Nov. 1, 1952	Total	6.16 mr
Bikini, USA	Mar. 1, 1954 (beginning)	Mar. 13, 1954 to Sept. 16, 1954	0.92 mr
		Sept. 20, 1954 to Jan. 6, 1955 (interpolated)	0.92 mr
		Jan. 6, 1955 to Feb. 15, 1955 (deposited)	0.38 mr
		Extrapolated to future	20.30 mr
		TOTAL	28.68 mr

* Adapted from Harwell Report AERE-HP/R 1701 (June 1955).

Particles of large size tend to plummet earthward in the local fall-out. Japanese studies on the Bikini fall-out dust showed that the particles were irregular granules with an average diameter of 250 microns. This corresponds to the fall-out at about 120 miles from the test site.

Practically, very little is known about the behavior of small particles dispersed in the stratosphere and lower air strata. We have evidence from the eruption of Krakatoa and some data from dust storms but very little dealing with the dynamics of ionizing particles. The result is that one is restricted to measurements of the ultimate fall-out on the earth's surface. For example, we have some U.S. data on continental bomb tests.[3] Unfortunately, very little information is available about the case of superbomb detonations.

Lacking specific data about the acrobatics of bomb products in the atmosphere, we are forced to make estimates on the basis of quite a number of assumptions. For example, we shall assume uniform fall-out in the Northern Hemisphere. We shall assume that 10 per cent of the fission products come to earth at remote locations at an effective time of three months. Calculations show that under these assumptions a 10-megaton fission yield detonation produces a maximum lifetime dose of 0.008 roentgens. In other words, this is the theoretical maximum radiation dosage that anyone in the Northern Hemisphere would receive from the detonation of a 10-megaton fission yield weapon if the irradiation period is from 3 months to 50 years after detonation.

This value of 8 milliroentgens per megaton of fission products in global fall-out (or per 10 megatons of fission yield in the superweapon) is an average value which would be subject to wide variations of at least a factor of ten. Again we stress the fact that the average value is the only one calculable under the variable conditions involved in fall-out.

Now we must consider what factors modify this maximum lifetime dose.

First: The estimate of the lifetime dose has been made upon an integration of the $t^{-1.2}$ decay rule for fission products. Actually, the $t^{-1.2}$ law is not obeyed after 3 months.[4] Relatively few radioactivities constitute the effective fall-out at the time periods involved in remote deposition. The principal contributors to gamma dosage within the first year are 35*d* Nb^{95}, 65*d* Zr^{95}, 42*d* Ru^{103}, and 30*d* Ce^{141} with Ru^{106} and 275*d* Ce^{144} predominating thereafter (95 per cent of the gamma activity at three years will be due to these two nuclides). Ten years after the detonation the gamma activity will be dominated by 33*y* Cs^{137}.

Second: Weathering will undoubtedly become increasingly important after the first month in reducing the surface dosage from the fall-out. Of course, this will depend upon the local environment and weather conditions. Heavy rains will tend to sluice off the fission products from hard surfaces. Normal precipitation and ground action will "soak up" the fission products in surface soil. One would expect that a surface layer of fission products would descend roughly an inch into the ground in one year. To this natural decontamination one would have to add whatever man could do by way of artificial decontamination.[5] The extent of the latter would probably depend upon the state of one's organized society following a nuclear war.

Third: Dosage has been estimated on the basis of 24 hour per day exposure to persons completely unshielded from the radiation. Actually, variations in terrain serve to cut down the dose.[6] Moreover, there will be local nonuniformity of fall-out due to micrometeorology and structures. Most people spend at least half a day indoors so that structural shielding enters into dosage calculation.

Fourth: Atmospheric "hold-up" of particles less than 10 microns in diameter will occur. Very high-yield explosions will puncture the stratosphere with the result that bomb debris will be held suspended in the upper air. In contrast with low-yield explosions where the first trajectory of the bomb cloud produces the main surface dosage, the high-yield bomb will produce gradual accumulation of surface dosage over a period of years.

Considerable fractionation of the fission products should be expected, particularly in the case of isotopes like strontium-90 which has a gaseous predecessor.

All the foregoing considerations usually tend to decrease the dosage. However, where natural forces act to concentrate the fission products then dosage rate can be increased. For example, a concentration mechanism could be cattle-grazing over several acres of pasture, collecting 50 or more pounds of grass per day. In such a case, the dosage would be internal. Since it would be quite variable, it has been excluded from these estimates.

Taking these factors into account it seems reasonable to estimate the life-

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[2] See H. L. Andrews, "Radioactive Fall-out from Bomb Clouds," *Science,* **122** (September 9, 1955), 453.

[3] M. Eisenbud and J. H. Harley, *Science,* **121** (1955), 677; **117** (1953), 141.

[4] See F. H. Clark, "Decay of Fission Product Gammas," *Nuclear Development Associates Report* (December 30, 1954, Revised February 15, 1955), pp. 27–39.

[5] See "Radiological Recovery of Fixed Military Installations," *U.S. Naval Radiological Defense Laboratory Report,* August 1953).

[6] J. E. Hill, "Effects of Environment in Reducing Dose Rates Produced by Radioactive Fall-out From Nuclear Explosions," *Rand Corp. Research Memorandum—1285-1* (Sept. 28, 1954).

time dose as the order of 0.002 roentgens or two milliroentgens per megaton of fission product fall-out.

Sir John Cockcroft has estimated[7] that the actual fall-out from all bombs detonated to date yields a total dose in Britain of 0.03 roentgens (in open countryside). A summary of British remote fall-out measurements from atomic bomb tests appears in Table 1 and corresponding data for multimegaton detonations appear in Table 2. Data on pre-1952 Pacific tests and the Soviet summer tests of 1953 are not available.

Let us now consider the radioactive aftereffects of a nuclear war involving the detonation of twenty 30-megaton fission yield weapons detonated close to the surface over a nation with an area of, say, 3 million square miles. If *half* of the fall-out took place over the nation and were uniformly distributed this would produce a radiation level of 0.1 kiloton equivalent of fission products per square mile. The corresponding eternity dose for unprotected people would be several hundred roentgens depending upon the proximity of the people to the explosion point. Considering a total population of 100 million survivors and an average dose of 100 roentgens (allowing for shelter) this would amount to a total dose of 10 billion man-roentgens. Allowance is made for the fact that people close in to the explosion sites would be overexposed and could not be considered as survivors. The *global* fall-out from this nuclear attack would be expected to produce an average dose of 0.1 roentgens to inhabitants of the Northern Hemisphere. Allowing for fluctuations, this might run as high as one roentgen in the middle latitudes. A total global dose of 100 million man-roentgens would be expected beyond the borders of the attacked nation.

A home country staging a large-scale nuclear attack upon a distant target complex would thus run little risk from the backlash of nuclear radiation. For example, Russia could launch a nuclear blitz on continental USA without exposing its homeland to a health hazard. Indeed, the genetic risk would not seem excessive since the total dose would probably not greatly exceed the annual natural background dose, which is about 0.1 r per year (see Appendix). On the other hand, should Russia undertake nuclear warfare in Western Europe then the consequences for Russia would be more serious.

The attacked country suffers not only the direct ravages of nuclear war but also is exposed to massive radiation doses of serious genetic consequence. Of course, the *attacking* country would also be exposed to the same radiation dosage should a policy of "massive instant retaliation" be implemented. Actually the genetic considerations do not depend on exactly who is irradiated. The world's populations will probably have mixed and intermarried many times before the last of the detrimental mutations is finally eliminated by some genetic death after hundreds of generations. Even the populations of the more lightly irradiated Southern Hemisphere would stand to suffer eventually.

The biological effects of specific fission products such as radioiodine and radiostrontium place them in a category quite apart from gamma-emitting fission products. Where concentration mechanisms exist to accumulate fall-out from a large surface, a significant internal hazard may be present. In his speech[8] of September 24, 1955, Dr. W. F. Libby defines the radiostrontium hazard. His critical value of 5 curies per square mile, coupled with a fission product fall-out of 5 megatons, means that an area of 150,000 square miles could be rendered dangerous to human habitation for several years. Actually, fall-out would occur over a smaller area with correspondingly larger concentrations of strontium-90.

One should not exclude the possibility of a "rigged" nuclear weapon or a radiocontaminant. The much discussed cobalt or C-bomb falls in this category. A comparison of the radioactivity produced by a superbomb of the March 1, 1954 type with a cobalt bomb leads the writer to believe that the former is a much more potent fall-out bomb. Cobalt suffers in the comparison from the fact that it is a "dead weight" additive to the bomb whereas uranium is pure "pay load" since it contributes to the blast-heat punch of the bomb. Freshly born fission products produce higher radiation intensities in the local fall-out than would cobalt. The long half-life of radiocobalt (more than 5 years) is a serious military drawback. First, denial of territory is seldom a military requirement for a period as long as a decade. Second, the long-term persistence of cobalt fall-out would be undesirable in the event of remote fall-out. Using such a weapon would be to invite "lash back."

All things considered, it would appear that the uranium superbomb is the most potent fall-out weapon. The official silence of the AEC with respect to the cobalt bomb has led many to assume that the C-bomb is a stockpile item in our nuclear arsenal. It would not appear discordant with the national security for the government to put forth a definitive statement on the cobalt bomb.

When the March 1, 1954 superbomb fall-out stirred up world-wide interest in radioactive hazards, Sir Winston Churchill sought to reassure the House of Commons. "My impression is that this biological aspect tends to be greatly exaggerated," the Prime Minister said, somewhat infirmly, for he had later to confess that he was not privy to U.S. bomb developments. However, Churchill added:

"If it was proved that a very large number of hydrogen explosions would, in their cumulative effect, be detrimental to the health or even the life of the whole human race without any need for a declaration of war, in itself, the effect would certainly afford a common interest between all men rising above military, political, or even ideological differences."

Remote fall-out from even a large-scale nuclear bombing would not appear to be a global hazard to humanity. Nonetheless, this would seem to be an academic point, for the immense lethality of the local fall-out makes the superbomb into the kind of compelling force which Churchill had in mind. Military leaders and political figures in this nation have been slow to perceive the revolutionary character of fall-out. In the Pentagon many still look upon fall-out as an unpredictable "bonus" and maintain that blast and heat are the real military effects of nuclear weapons. This view is changing, however. Gradually, the true dimensions of radioactivity are beginning to take shape. When the military and political appreciation of fall-out becomes realistic then the superweapons will begin to approach the par value set by Sir Winston Churchill.

APPENDIX

The best and most recent summary of the radiation dosage from the natural background is that given by Dr. Willard F. Libby in *Science*, *122* (1955), 57. Experimental data are given by L. D. Marinelli *et al.* in *The Amer. J. Roentgenology 73* (1955), 661, and by R. M. Sievert in "Measurements of Low Level Radioactivity, particularly the Gamma Radiation from Living Subjects" Paper 8/P/792 presented at the Geneva Conference on the Peacetime Uses of Atomic Energy.

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[7] Address to the Parliamentary and Scientific Committee, April 20, 1955. Published in *Nature*, May 21, 1955.

[8] Willard F. Libby, "The Radioactive Fall-out," Fourth Annual Conference, U.S. Civil Defense Council. This is an excellent discussion of biospheric contamination.

One divides the radiation dose into two sources, those internal and those external to the human body.

Dr. Libby estimates that the natural radioactivity of the human body averages:

Radiopotassium	19 mr/yr
Radiocarbon	1.5 "
Radium (bones only)	6.7 "

which totals 27 milliroentgens per year.

The external radiation consists of that found in cosmic rays, that emanating from gaseous radioactive products, and that incorporated in the earth's crust or in building materials.

Cosmic radiation varies with altitude and latitude. Considering a surface intensity of 35 mr/yr, then the corresponding rate for an altitude of 1 mile is 50 mr/yr; 100 mr/yr at 2 miles and roughly 200 mr/yr at 3 miles. The latitude effect, which is not so pronounced, yields higher radiation levels the farther one goes from the equator.

Typical sedimentary rock produces an annual dose of about 80 mr while ordinary granite yields roughly 145 mr. Unpublished measurements of B. Hultqvist on Swedish dwellings shows a variation of from 80 mr/yr to 200 mr/yr depending on house construction. Some houses showed dosages of 0.5 r/yr. Variations in interior measurements are found depending upon the degree of ventilation of the dwelling.

Editorial: Genetics in Geneva

(*Continued from page 316*)

tion, and that the scientists who came to the congress as individuals will stay and leave as such. I believe, however, that had this conversation been with a Russian *scientist*, the best of them would have had full understanding for the traditional way of exchanging scientific experience and ideas "from man to man" rather than "from nation to nation," and wished that someday they, too, would have the opportunity to come to an international conference not as "delegates," but as voluntary participants.

It was perhaps inevitable that the first international conference on nuclear energy should have assumed the external form of an assemblage of national delegations. Probably the majority of American *scientists* who came to Geneva with the official label of "delegates," felt themselves not as such, but as individuals, free to express their own views (to the extent allowed by the obligation not to reveal classified information). The situation was, however, different for those who were by training—or have become by actual occupation—*technologists* rather than *scientists*. Since 1942, atomic technology has been developed in America and elsewhere by large national teams working under central direction; with the result that at present, international communication and cooperation in this area can be only on a team-to-team basis, and subject to close governmental control. Despite the emergence of a private atomic industry, it seems that for some time to come at least, atomic power production is bound to remain a nationally-owned or nationally-controlled enterprise; international cooperation in this area will therefore remain a matter of bilateral or multilateral conversations and agreements between national bodies.

In no other area is basic science so closely related to industrial application as in nucleonics. Like the first bombs, the first reactors were designed and built by theoretical physicists; these "fathers of atomic energy," or their pupils, still play a leading role in most atomic power projects, despite the emergence of a new professional group of "nuclear engineers." The active role of "pure" scientists in the construction of nuclear machines (and the necessity of these machines for pure research) has made the traditional separation of "science" from "technology" very difficult—and inadvisable—in this area. Yet, the research aspects of nuclear science need, for their fullest development, a different spiritual climate and a different administrative set-up from the applied aspects. When the Geneva Conference was first planned, this distinction was considered—at least, by some of the planners—as justifying the division of the Conference into two parts: a nuclear power conference between governmental delegations, and a nuclear science symposium of the traditional free-for-all type. We do not know at what stage—or for what reasons—a decision against such a division was made, with the result that everybody coming to Geneva was transformed into a "delegate" (or, at least, an official "adviser" to the delegation). It is easy to suggest valid reasons for this decision. However, the Muller incident points to the advisability of avoiding, in the future, the monopolization of international cooperation in nuclear science by government agencies. The AEC (and many other governmental scientific bodies as well) has succeeded since the end of the war, in creating in its laboratories conditions permitting individual initiative in uncommitted, fundamental research. Any tendency the administration of these laboratories may have occasionally displayed toward excessive centralized control, and directing of research toward definite, practical objectives, is rendered less dangerous by the growth of nuclear research facilities in universities and nongovernmental research laboratories, which are free in the selection of their subjects and the direction of their work (even if they usually are dependent upon government money). It is this type of research that carries on the traditions of science, and promises the most for its future progress—in particular, for its contribution to the spiritual civilization of the free world.

A similar alternative to government-directed international activities, in the form of free individual communication and cooperation between scientists, is also needed if science is to make its full contribution to world civilization and peace. The scientific community of America, as well as the scientists of other countries (including, in our belief, the majority of those of the totalitarian countries) cherish the hope that in the future, the exchange of ideas among scientists in *all* fields—including nuclear physics—will be brought back on its traditional individual and voluntary basis, with no national delegations "opposing" or "competing."

This may mean, in fields such as nuclear physics, a somewhat artificial and awkward separation of science from technology, where the two are closely related and interdependent. For the "pure" scientists, it may also mean less luxurious travel, and fewer (or more modest) receptions and banquets (except perhaps in Russia)—but most scientists will not mind this sacrifice.

—E. R.